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EFFECT OF PULSED LASER RADIATION ON AMORPHOUS SEMICONDUCTOR FILMS

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ABSTRACT

The possibility of writing-in by laser on the film of composition Te_{81} Ge_{15} As_4 was investigated. It is possible to write spots by short laser pulses. The time of writing was 3,5 μsec, the minimum energy density was 70 mJ/cm^2. The temperature values predicted by equation of heat conduction show that the process of the writing can be ascribed to the recrystallisation of the melted substance.

РЕЗЮМЕ

Нами были обследованы возможности записи на пленке с составом $Te_{81}Ge_{15}As_4$ с помощью лазерового излучения. Нанесение кристаллических точек нам улалось осуществить посредством коротких импульсов лазера; длительность импульса равнялась 3,5 μсек, а минимальная мощность 70 милиджоул/см^2. Значения температуры, полученные из уравнения теплопроводности, показывают, что запись является результатом кристаллизации, протекающей вслед за расплавлением вещества.

KIVONAT

Megvizsgáltuk a Te_{81} Ge_{15} As_4 összetételü filmen a laseres beirás lehetőségeit. Sikerült megvalósitani a pontok irását rövid laserimpulzusokkal, a beirási idő 3,5 μsec, a minimális energiateljesitmény 70 mJ/cm^2 volt. A hővezetési egyenlet megoldásából kapott hőmérsékletértékek azt mutatják, hogy a beirás az anyag megolvadása után bekövetkező kristályosodás eredménye.

INTRODUCTION

Optical absorption constants of the amorphous semiconductor Te-Ge-As system are remarkably dependent on the process of quenching and annealing. On annealing at temperatures below the melting point for instance the absorption edge shifts to shorter wavelengths. A similar edge shift occurs upon laser radiation, producing a transparent spot on the thin film. Their fast spot-writing capability and erasibility render amorphous semiconductors well suited to use as two-dimensional, high-bit-density 10^7 bit/cm^2 optical memories. Many investigations have been performed on the electrical seitching and memory effects in chalcogenide amorphous semiconductors since Ovshinsky's first observation of both effects /1/. In addition Feinleib and Ovshinsky /2/ have made reflectivity studies of the Te-Ge-As system, while Asai and Maruyama /3/ have reported that laser radiation caused a phase change in Te-Ge-As glass. Reported in this paper are our preliminary experiments on a rapid laser-induced crystallization of $Te_{81}Ge_{15}As_4$.

1/ ABSORPTION EDGE SHIFT

Samples of composition $Te_{81}Ge_{15}As_4$ were evaporated onto silica sheets to a thickness giving an optical extinction of about 1. The measurements were made on a Unicam SP-700 spectrophotometer with a silica sheet of the same thickness for reference. The change caused by heating in the absorbancy of the chalcogenide layer in the wavelength region between 186 and 3500 mm is shown in Fig. 1.

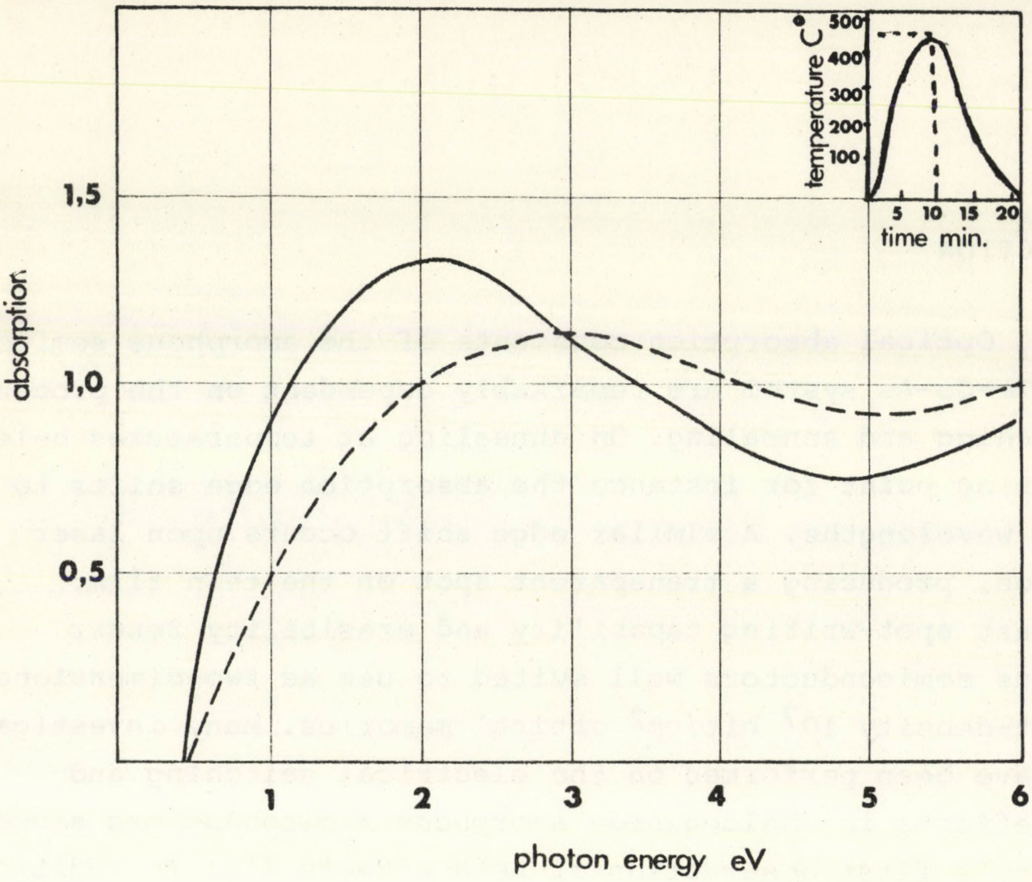

Fig.1. The change in absorbancy of the calchogenide film caused by heating. /Dotted line/ 22°C, /solid line/ after heating according to the insert temperature profile

From the spectra an activation energy of 0,5 eV can be deduced, in accordance with the data reported in the literature. The heat treatment caused a pronounced modification of the absorption spectrum; not only was the absorption edge shifted towards shorter wavelengths but the maximum absorbancy was increased as well.

2/ WRITING-IN BY LASER

The shift of the absorption edge caused by heat treatment also occurs under the effect of laser radiation. For writing-in with laser a pulse of appropriate energy must be chosen, for at too high energies the film evaporates, while at lower energies, on the other hand, no detectable change is produced.

In our experiments the light source was an He-Ne laser. The intensity of the light was regulated by a polarizator and mechanical modulation was applied to provide pulses of at least 3,5 μsec duration. The laser beam was focused on the sample with a 40-power microscope objective lens /Fig. 2/.

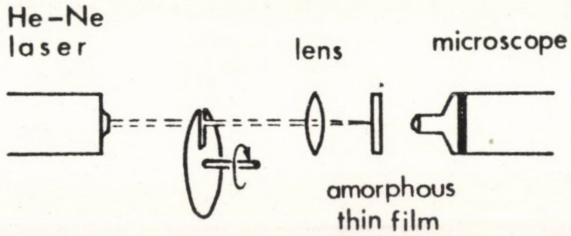

Fig.2. Schematic representation of the optical system

The experimental results are summarized in Table I.

TABLE I

Laser power mW	Pulse duration μsec	Energy density mJ/cm^2	Observation
10	6	360	
7	6	210	burned spots
6	6	180	
6	3,5	150	crystalline
5,5	3,5	98	spots with
5,3	3,5	94	burnt center
4,9	3,5	85	
4,8	3,5	80	crystalline
4,7	3,5	79	
4,5	3,5	78	spots
4,2	3,5	70	
3,8	3,5	65	no change

A written spot was obtained only with laser radiation of the right power and pulse duration. When the laser power was high, the spot was burnt out; when it was low, no change in transparency was observed. The morphological changes caused by laser pulses in layers were photographed with a Jeol JSM-V3 scanning electron microscope in secondary electron mode /Figs. 3 and 4/.

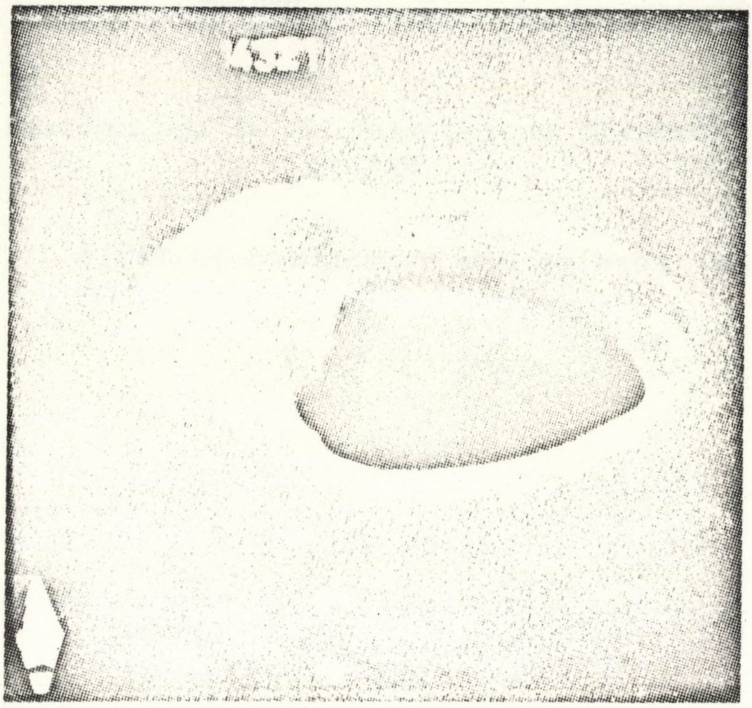

Fig.3. Laser-induced spot in the calchogenide film and the surrounding matrix

Enlargement: 30,000; sample deviation 45°
The energy density 180 mJ/cm^2 was in this case too high and a 1,5 μ diameter spot was burnt out

Fig.4. Crystalline spot written by a laser beam of appropriate energy

Enlargement: 30,000 sample deviation
The spot is 2 μ, in diameter and possess sharp boundaries

3/ TEMPERATURE PROFILE

The temperature profile can be obtained by solving the following differential equation of heat conduction /7/

$$\frac{1}{\kappa}\frac{\partial T}{\partial t} = \frac{P_o}{K.h} + \nabla^2 T \qquad /1/$$

where $\kappa = K/\rho.c$

K = thermal conductivity

ρ = density

c = specific heat

P_o = laser flux density

h = thickness of the film

We shall discuss only the region where the second term on the right-hands side of the equation is negligible. If we further neglect the effect of the substrate, the temperature is given by

$$T = P_o T/\rho . c . h + T_o \qquad /2/$$

For short pulses, t can be replaced by the pulse duration t_p .

Taking the values $\rho = 5{,}625\ g/cm^3$; $c = 0{,}5\ J/g^oK$; $h = 10^{-5} cm$; $t_p = 3{,}5.10^{-6}$ sec; $P_o = 4{,}2\text{-}4{,}9\ mW/3.10^{-4\ 2}\ cm^2$, we find $T = 580\text{-}630^oC$.

This temperature range with the known melting point of chalchogenide /$\sim 560^oC$/ the process of the writing can be ascribed to the recrystallisation of the melted substance.

CONCLUSION

These preliminary experiments on the structural transformations of the Te-Ge-As film under the action of laser radiation indicate that it is possible to write transparent spots of 2-3 μ diameter with the aid of an He-Ne gaslaser modulated by a mechanical shutter. For a writing time of 3,5 μsec, a minimum energy density of about 70 mJ/cm^2 is required. This laser-induced change can be used to prepare optical memories of bit densities up to 10^7 bit/cm^2. The conditions of writing and erasing are being further studied.

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